Fish production and the management of natural resources: the role of aquaculture for economic-environmental sustainability[1]

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Jel classification: F130, Q170, F310

Abstract

Fish fauna is a renewable and mobile natural resource whose reproduction and movements are still relatively uncontrolled by man. The maintenance of a satisfactory level of sea fishing activities requires a healthy marine environment if we are to preserve the species. After comparing two different natural systems of food procurement (livestock and fish rearing) and highlighting the advantages of fish farming, with respect to pasturage for the production of low-cost animal protein, the analysis addresses the sustainability of different productive systems in the fisheries sector. An Italian case study is presented on a special form of extensive fish farming, vallicoltura, which demonstrates a compatible use of the highly sensitive lagoon environments.

Résumé

La faune piscicole représente une ressource naturelle, renouvelable et mobile, dont la reproduction et les déplacements ne sont encore que peu contrôlés par l'homme. Maintenir un niveau satisfaisant d'activité halieutique exige un environnement marin salubre propice à la conservation des espèces. Après une comparaison entre deux systèmes naturels d'approvisionnement (élevage de bétail et de poisson) qui permettra de souligner les avantages de l'élevage aquacole sur les pâturages pour la production de protéines animales à bas coût, l'analyse se centrera ensuite sur la soutenabilité des différents systèmes de production dans le secteur piscicole. Il sera présenté un cas italien dans lequel une forme particulière d'élevage aquacole extensif, la valliculture, constitue une utilisation compatible d'environnements particulièrement sensibles comme l'est le milieu lagunaire.

1. Introduction to sustainable development

It would be desirable if, in the future, men were to adopt a sustainable approach to development, such as to safeguard the environment and respect natural resources by maintaining their stocks over time. The principal objective of development is to satisfy needs and aspirations but the growth in the number of goods is not always sufficient for this purpose. The system of development hitherto pursued has led to a breakdown in the equilibrium between biological time and historical time. Biological time refers to the timescale used to represent biological evolutionary processes, whose units are measured in millions of years. On the contrary, men, in general, use resources with reference to a timescale that follows the rhythms of development and production needs. Unfortunately, this is often unsustainable.

Biological time is also a measure of the future. Thus, the breakdown in the equilibrium is bringing about planetary variations within a timescale short enough to produce accelerations in the biological clock (Tiezzi E.,1988). For example, a numerical increase in the population can increase pressure on non-renewable and renewable natural resources and slow down the quality of life, exacerbated by an often-inequitable distribution of goods and services. Sustained development, on the contrary, entails that demographic growth is in harmony with the development of the productive potential of the system. In practice, sustainable development requires that the rate at which natural resources are depleted does not preclude future opportunities or if such preclusion is necessary that it be as limited as possible. A "sustainable" model, therefore, can be defined as "a process of change in which the exploitation of resources, investment trends, the orientation of technological development and institutional changes are in harmony with one another and able to increase the present and future potential to satisfy human needs" (World Environmental and Development Commission, 1988).

However, sustainable development also implies other consequences and not just those entailed by economic growth alone. It calls for a change in the content of the growth itself so as to reduce the intensity with which materials and energy are used and make the environmental impact of growth more acceptable.

The concept of environmental resources as a "natural capital" now accepted by many economists, is important for understanding the economic role played by the environment, in terms of sustainability, in the development process. If it is accepted that natural resources as whole represents assets able to provide a not unlimited flow of goods and services, we can treat such assets as if they were a financial capital and thus assign a certain profitability to them (determined by the natural laws that govern environmental processes). Such assets can be periodically exploited, but only as regards the share that can be used without prejudic-

[1] The present study is included in the National Project, 5th Plan for Fishery and Aquaculture "The interactions between Fishery, Aquaculture and the Environment: Sustainable Development Models and the Impact of Sectoral Policies". It has been co-ordinated by Prof. G Trevisan.

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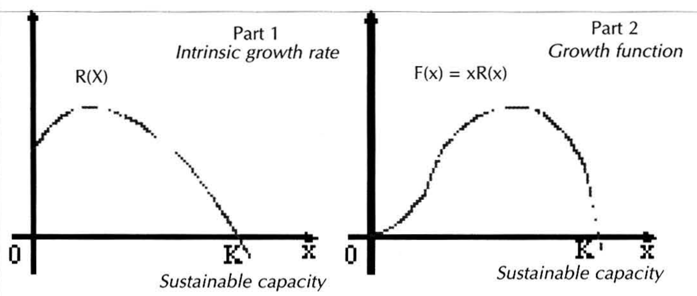
ing future consumption or diminishing the initial capital. The bank savings metaphor is useful for defining what takes place in nature as it concerns renewable resources. Thus, if an individual consumes more than the periodically maturing interest, which is the only useable share, he will prejudice his initial capital. If, for example, a natural resource (say 1,000 tons) is able to regenerate itself at an annual rate of 10%, exploitation cannot exceed this limit without compromising its natural renewable capacity. If anthropogenic activities subtracted 200 tons of resources per annum, in a period of only fifty years, the initial natural capital would be reduced to less than 50% (the capital in the first year is 1,000 tons and after five years it would be reduced to 389.5 tons) and after 8 years of activity the resource would no longer be able to satisfy man's needs. Of course, this very simple hypothesis does not take into account the complex and often non-linear relationship between the growth in biological components and economic growth. And, this is a particularly significant limit in the case, for example, of fishing: bio-economic models have recently been introduced to provide a better understanding of systemic phenomena.

The simplest dynamic model used to describe the trend over time of the quantity of a given renewable resource (i.e. able to grow and reproduce itself, for example, a forest and/or a fish population) introduces a set of natural and environmental factors that influence the growth dynamics of the resource (Antonelli G. et al, 2002). The quantity of the available resource is based on the following equation:

$$x(t+1) = x(t) + F(x(t)) - H(t) \quad (a)$$

where:
t: represents time, which is presumed to be made up of intervals or periods;
x(t): is the measure of the available resource (i.e. the biomass)
F(x): is the growth rate of the resource (difference between the birth and death rate) referenced to a given period;
H(t): represents the quantity of the resource removed in the time unit (in the case of fish resources it represents the fish caught).

Figure 1. *Growth functions of a natural resource: example of linearly diminishing growth*



Source: Our calculations, based on Antonelli G. et al "Modelli teorici e principi guida per uno sfruttamento sostenibile delle risorse nel settore della pesca" in Trevisan G. (edited by). Il prodotto ittico, Consumo, Qualità, Commercializzazione. Acts of II Study Conference, Venice, 11-12 October, 2000.

If, for example, the quantity removed from the natural resource were virtually zero, the growth dynamics would essentially depend upon the biological properties of the population in question and the characteristics of its environment. These factors are included in the function and the trend is usually assumed to be diminishing. This is because where there are few individuals, the external environment encourages a birth rate higher than the death rate on account of the abundance of food, space, hiding places, etc. The relationship, however, becomes inverted when population growth, as a result of environmental limits, (understood as a set of vital resources), provokes a reduction in the birth rate and an increase in the death rate.

Therefore, the trend in function F (indicated as xR(x)) is graphically in decline and, thus, can be represented as a parabola. An example is set out in figure 1. The value r = R(0) is termed intrinsic growth rate (part 1) and the value K=0 - in which R(K)=0 is defined as the sustaining capacity - is the value of the population where the growth rate is nil, insofar as the birth and death rates are in equilibrium.

In any case, given the value x (0) of the population over a certain time period t=0, if we know F(X):) we can calculate the quantity of resource x(t) in the successive periods t=1,2,3 or the temporal evolution of the quantity of the resource. They are two stationary states:
x = 0: is represented by the equilibrium of extinction (or non - existence);
x = K: is represented by the sustaining capacity.

From the definition of the equilibrium it follows that if the system were, in a given moment, to find itself in one of these two stages, it would be stable in subsequent periods as well. However, the two equilibriums behave differently if the value of the population is slightly altered with respect to the equilibrium value. Thus, in the case of X=0, a small increase in the resource will be amplified and thus the successive values x(t) obtained by repeating the function presented will definitively move away from the original equilibrium. In the case of the equilibrium x=K the endogenous forces of the system will tend to diminish each small movement, thus bringing the value X(t) back to the original equilibrium. This is because F(x) >0 to the left of x = K, and F(x)<0 to the right of x = K.

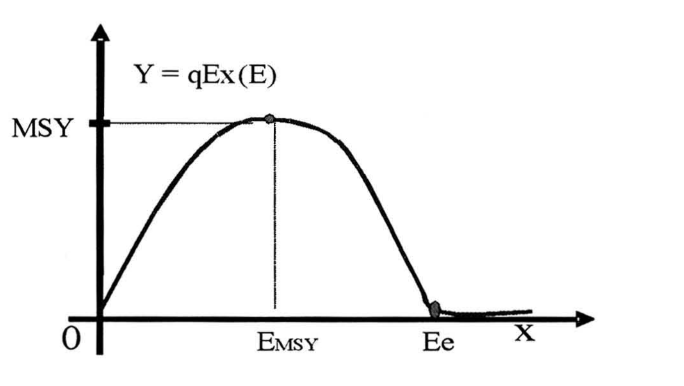
Therefore a single globally-stable equilibrium is achieved, that is, starting from any initial condition, the value of the population reaches the cited value of x=K after a certain period of time, which represents the long-term value.

However, the situation changes significantly when removals occur, which, in the case of fish population, can be defined as "the fishing effort" and, for example, will depend on the number of fishing boats and time dedicated to the activity. The equation (a) gives us:

$$H(t) = qEx(t)$$

where:
q: is the level of technology reached;

Figure 2. *Growth functions of a natural resource: example of the influence of the fishing force*



Source: Our calculations, based on Antonelli G. et al "Modelli teorici e principi guida per uno sfruttamento sostenibile delle risorse nel settore della pesca" in Trevisan G. (edited by). Il prodotto ittico, Consumo, Qualità, Commercializzazione. Acts of II Study Conference, Venice, 11-12 October, 2000.

E: is the fishing force and mainly depends on the number of fishing boats;
(t): is the time fraction dedicated to the activity.

The equilibrium value of (x) becomes a function of an effort inferior to the sustaining capacity $x = x(E)<K$ (figure 2). With the growth in effort E, the equilibrium acquires ever small values, until it reached zero with $E > Ee$ where Ee is the point beyond which fishing activity takes on the characteristics of unsustainability. This means that the higher the fishing effort, the smaller the equilibrium value and, that there will be a long-term evolution leading to the extinction of the resource, if the effort were to exceed the threshold value of Ee. With E_{Max} we intend to depict the maximum possible exploitability of the resource possible to keep sustainable production unchanged in relation to the sustaining capacity of the resource in question.

Some interesting relationships can be deduced from figure 2. The first is fundamental for production based upon renewable resources: a larger fishing force implies greater fish production in the short term, but in the long term the volume fished dwindles (with $E > E_{Max}$), up until its total extinction in the case of $E > Ee$.

The second indicates that, if we commenced from a condition of equilibrium with a given value E, when the latter is changed, a transitory period would be determined with non-equilibrium dynamics, to then reach a new equilibrium point, although an extremely negative one, such as the extinction of a resource.

Therefore the natural capital performs two fundamental functions for the economy without which anthropogenic activity would experience development difficulties. In particular:

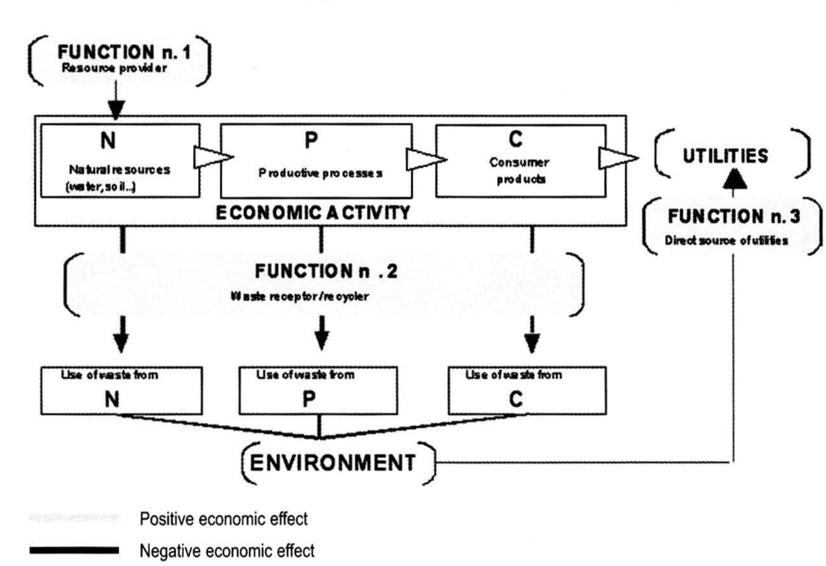
1. it is the principal source of resources and services from which the most important productive and consumption processes begin;
2. waste from productive and consumption processes returns to the ecosystem. If the latter did not possess an intrinsic capacity to assimilate and transform waste products into a new re-utilisable resource, the economic system would very quickly collapse.

Thus, if we did not include the environmental factor in any productive cycle, the activity would appear as a linear system. Production P (the result of production processes) is aimed at the creation of consumption goods C. The purpose of consumption activities is to produce utility for the individual. However, the productive system starts with the input into the cycle of goods of renewable and non-renewable natural resources (N). The picture, therefore, remains incomplete on account of the failure to take account of waste products (as will be indicated in the circular model) in the various phases of the process (of production and consumption).

A sustainable productive system can be achieved by moving from the linear to the circular model (figure 3). If the productive process is linked to natural resources, three new interrelated functions of the environment and the resources can be discerned, namely:
1) the supplier of resources;
2) the receiver of waste;
3) the direct source of utility.

Because they possess a value, these are economic functions. If they were sold and/or bought on the market they would have a price. Dangers arise from the erroneous use of the natural environment deriving from the fact that such functions and their values are not considered positive. Sustainable development, therefore, implies the choice of dif-

Figure 3. *Circular economic system*



Source: Our calculations, based on Pearce David W., Turner R.. Kerry, Economia delle risorse naturali e dell'ambiente. Il Mulino, Bologna, 1991.

ferent forms of behaviour to be observed by society according to the attention attributed to the protection of natural capital. However, if the concept of sustainable development is now accepted by the international scientific community, it is still possible to find extremely different types of behaviour within it.

2. Evolution of the fish-resources management theory

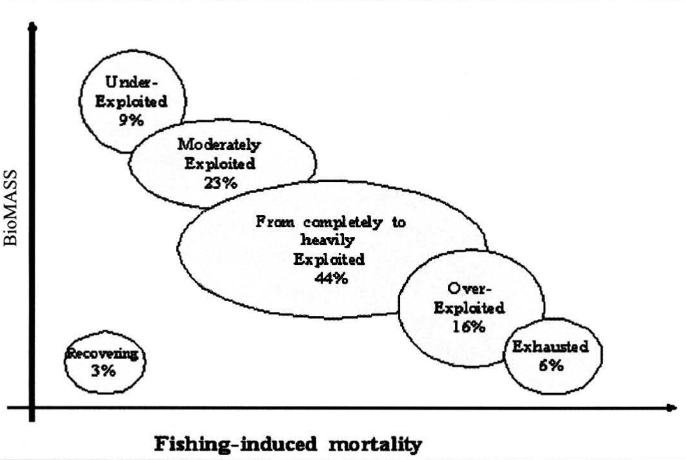
Fish fauna represents a renewable and mobile natural resource, whose reproduction and movements are still mostly outside men's control. Maintaining sea fishing activities at a satisfactory level calls for a healthy marine environment in which the species can be preserved. It follows that fishing must be regulated and managed in such a way as to protect marine ecosystems and safeguard resources.

The ecological impact upon coastal ecosystems of the excessive fishing effort has been higher than any other "disturbance" originating in human activity, including pollution, the deterioration of the quality of the water and anthropogenically-determined climatic changes (Jeremy et al., 2001).

In a study by Botsford et al. (1997) it was shown that 44% of world fish stocks were intensively or totally exploited, 16% over-exploited, 6% exhausted and only 3% of the stocks slowly recovering (figure 4).

The causes of this situation are in part to be found in the failure of the measures used to manage seawater fish populations, which at present are mainly centred on the certain target species and not upon the ecosystem as a whole.

Figure 4. *Level of exploitation of the world's seawater fish population in relation to biomass and fish death rate*



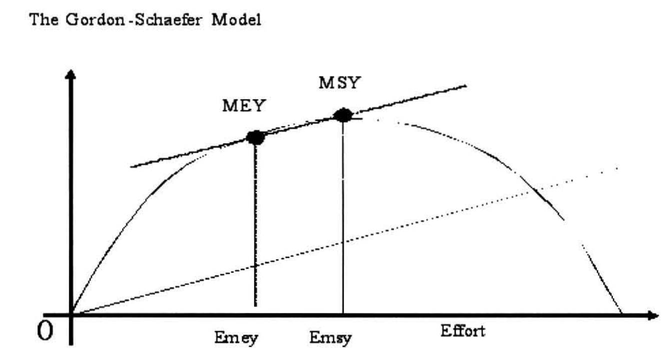
Source: Botsford et al., 1997

These management instruments are mainly based on three theories:

- Maintenance over time of the production of resources deriving from the exploitation of natural populations and ecosystems (Maximum Sustainable Yield)
- Maintenance over time of the profit deriving from the exploitation of natural populations and ecosystems (Maximum Economic Yield)
- Maintenance over time of the abundance of populations and the diversity of ecosystems.

The first of these models, described in the following paragraph, limits itself to considering the relations between the fishing effort and sustainable production. "Sustainable" qualifies the characteristics of exploitation. It describes a type of catch that will ensure the continuance of fishing activities. An enhancement of this model, also in the absence of regulation, takes account of expected returns. In this case it is easy to demonstrate that the economic optimum is represented by Emey (figure 5). It can also be observed that the equilibrium maximising profit does not coincide with MSY, that is with the maximum sustainable yield. In both models the approach adopted is "populationistic", exclusively based on fishing biology and derived from considerations based on a single exploited stock.

Figure 5. Maximisation of sustainable revenue



For over thirty years the concept of MSY was the basis for the management of fishing resources. In most cases it sets out to ensure profit maximisation for fishermen through the maximum possible exploitation, but to a degree compatible with the biological growth of the target species.

The use of the term "sustainable" for MSY has been shown to be inappropriate because on account of environmental fluctuations, the MSY catch, every year from a stock, can lead to unexpected and unforeseen negative consequences.

In an attempt to remedy the numerous situations of overexploitation an instrument has been introduced in recent years (a system of transferable fishing permits) to regulate the fishing effort[2]. Many authors believe that the sole criterion of economic efficiency is often insufficient to guarantee the survival of fish resources and that, therefore, management policies should address the question of the prevention of the extinction of the species and preservation of

[2] The system of transferable permits provides that the stock of a given species will be estimated and that later the maximum quantity to be caught will be fixed (the Total Allowable Catch). The TAC is broken down among fishermen who can exclusively fish the part assigned to them.

the maximum level of biodiversity of an ecosystem (Granzotto et al, 2001).

In addition, it should also be noted that the management systems hitherto adopted are solely based on the observation, monitoring and knowledge of a single target species. If we wish to speak about sustainable development in the future it is necessary for us to consider all the resources involved in fishing activities and the damage, including indirect damage, that this can cause. Therefore, the management of fish resources moves from the "fishing biology" level of a single or a few target species to the ecosystem, "fishing ecology" level, which not only considers the knowledge of the target species but also the effects upon non-target species and the physical environment as a whole.

3. World fish production: various levels of food sustainability

World fish production in the last decade has offered two different growth patterns referring, respectively, to fishing operations and fish farming.

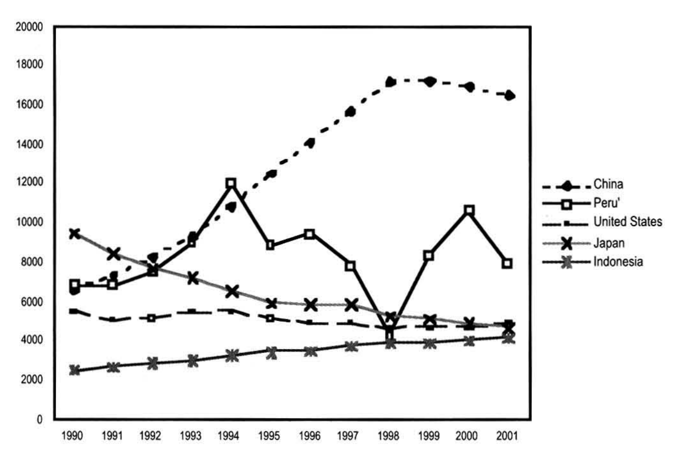
In the case of catches, the latest trend has levelled out at a high but hardly improvable level on account of the relations between the catches and the growth in the resources, and these, in their turn, have led to a progressive rise, throughout the world, in "fishing bans", the elimination of certain fishing techniques that destroy the ecosystem and the limitation on the fishing of certain species. In 2001, the overall world value stood at about 92 million tons, representing an 8% increase with respect to 1990 (FAO, 2004).

The fish produce obtained from fishing activities is primarily accounted for by East Asian, United States and Peruvian companies (figure 6). In fact, the first five countries produce 40% of the entire world catch, which rises to 58% if the first ten producer countries are also considered.

The breakdown of the catch shows the prevalence of marine fish species: herrings, sardines and anchovies historically constitute the principal component (figure 7).

It is also interesting to note that catch growth patterns in

Figure 6. *Catch patterns: firts 5 countries (000 tons)*



recent years have more or less stabilised in relation to the biological re-population capacity and laws imposed by the various country. The only exception is China, which is the only country in the world to have recorded a net increase up until 1998. After this date its production levelled out, but the country still ranks first in fish production. This trend is also true in the case of the analysis of groups of fish and of the single species.

Instead a quite different picture emerges for fish-farming development patterns over the same reference period. The fish produce obtained from fish farming facilities, which recorded an 11% growth in the last decade, is the food sector with the highest and most constant growth. Production volumes rose from 13 million tons in 1990 to 31 million tons in 1999 while the most recent estimates indicate that production from fish-farming facilities may outstrip livestock production in the first years of the new millennium. This undoubtedly significant growth indicates a real change in consumers' eating habits.

In the last century the world made use of two natural systems for food procurement: pastureland and ocean fishing to satisfy the growing demand for animal protein. Higher levels of meat and fish production require either higher concentrations of livestock on pastureland or fish in fish farms or an increase in production facilities. Therefore, the efficiency with which livestock and fish transform cereals into protein must be redefined in relation to production trends and the correlated diet emerging from consumer demand.

About 7 kilograms of grain are needed to fatten livestock by 1 kilogram, while fish can increase their weight by 1 kilogram with, in some cases, less than 2 kilograms of nutrient. In addition, considering the fact that water scarcity has become too serious problem to be ignored, we should remember that 1 ton of grain requires a thousand times more water by weight. Thus conversion yield, clearly in favour of fishing, also increases its value when the relative savings in water consumption are considered (including the need for water in fish farm rearing tanks). Albeit an introductory overview, these facts suffice to demonstrate the advantage of fish farming over pasturage in the production of low-cost animal protein.

Unlike meat production, which is concentrated in industrialised countries, about 85% of fish farming produce is produced in developing countries. In 1998, China accounted for 21 million tons with respect to the world total of about 31 million (amounting to about 68%), followed at a great distance by India with 2 million tons. Among industrialised countries, the three leaders are:

1. Japan: production is about 800 thousand tons, mainly represented by premium species such as molluscs and oysters. At present its inhabitants (about 125 million) consume about 10 million tons per annum (amounting to about 80 kg of fish per capita).
2. The United States: production is about 450 thousand tons of which most is catfish.
3. Norway: salmon represents the most important species

and overall production amounts to about 400 thousand tons.

Although at least 220 species of fish and shell fish are husbanded, one dozen species alone account for most of the world trade. As concerns fish, five species of carp (virtually an exclusive Chinese production) occupy the first place, whose combined production represents about 11 million tons (1998). Among the shellfish, Olympia oyster, followed by Yesso molluscs and the blue mussel predominate.

As stated, the farming of some species of carp, included in the agricultural - food chain according to the specific needs of the territory and its resources, is particularly important in China. Silver carp and bighead carp nourish themselves by filtering water and feeding on phytoplankton and zooplankton. Field carp feeds on vegetation, while the common carp is virtually omnivorous. Most of the fish farming activities in China is integrated with traditional agricultural activities. The sediments and residues from stock rearing are used to fertilise the tanks thus enhancing the proliferation of plankton.

In the United States, catfish is the top species in fish production. We should also remember that the ratio of nutriment to growth, certainly one of the lowest, and thus the most convenient among farmed species, is 1.6/1. Recently catfish consumption overtook lamb and mutton (about 1 kilogram for each citizen per annum). In the Mississippi area fish farms have been set up with an overall extension of about 45 thousand hectares, accounting for 60% of total production.

4. The sustainability of productive systems: a comparison between fish farming and fishing

The term fish farming refers to the set of activities and technologies for the production of aquatic organisms by controlling one or more phases of their biological cycle in the environment in which they develop. In addition, fish farming has stimulated an important process of specialisation so that all the produce from this activity is earmarked for human consumption unlike fishing where a significant part of the catch is still used for non-food purposes.

Fish farming activities can have a negative impact on natural resources. It can modify habitats, use areas that are typical feeding grounds for quality marine species in their early development and prevent some adult fish species (eels, mullet, seabass, seabream) from returning to the sea to reproduce as fish farming facilities are placed at the mouths of lagoons, thus reducing the availability of eggs and larvae. Furthermore, the effects on autochthonous communities and the risks of genetic pollution are well known in cases of fish escaping from fish farming facilities, and also in this circumstances the consequences can be disadvantageous for fish at large.

Nevertheless the expectations generated by fish farming in terms of its contribution to a future fishing policy are such that we can forecast it playing a role in the reduction of the fishing effort by substituting the latter in catering for the growing demand for fish produce, as well as offering future opportunities such as, for example, restocking fish and sea farming models that in the case of artificial barriers can attract and protect quality marine species.

Furthermore, intensive sea farming facilities, as is known, attract high-value fish species, and this effect can be put to good use for the conservation and protection of some age-categories of sea fish. In other words, work should be undertaken to optimise the competitive opportunities offered by the relations between fishing and fish farming in order to simultaneously improve the way the sea is used and conserved.

According to a recent report by FAO, as stated earlier, the annual rate of increase in fishing will soon reach zero worldwide while the average catches, relative to conventional marine resources, are by now close to the ceiling of maximum stock exploitation. Consequently, traditional fishing activities do not seem able to make further increases, without irreversibly impoverishing resources. If we analyse the fishing trends in the most important marine environments in relation to the areas of exploitation and the maximum potential level achievable, we can note a marked decline in the percentage rate of variation, which, in the case of the Atlantic Ocean, has already amply exceeded the threshold of exploitation, while the Pacific Ocean has reached the threshold of the maximum potential level. The Indian Ocean and the Mediterranean appear to be susceptible to a further increase of, respectively, 4% and 2% before reaching the maximum exploitation threshold.

However, it is worth recalling that if fishing is the major factor in fish stock depletion, an unequivocal relationship between stock exploitation and reduction has not been demonstrated as other environmental causes (pollution, changes in the nutrient chains, variations in thermal systems) can also be factors in the impoverishment of fish resources.

The concomitance of such factors, together with the progressive increase in food demand was the first cause for the development of fish farming. In recent decades fish-farming operations have recorded a constant and regular increase worldwide.

With regard to the species reared in fish farms, it should be noted that, although a limited number of species have undergone genetic improvement processes, most of the aquatic organisms reared are very similar or identical to their counterparts in nature. This calls for sound biodiversity protection measures, as the actual phase of water species domestication can be compared to that of terrestrial animals whose husbandry first began some hundreds of years ago. From the quantitative point of view, the number of the taxa of aquatic animal organisms subject to husbandry is in continual increase and the potential is still notable as studies on the techniques of reproduction and farming have only been limited to species of greatest commercial interest.

It is obviously important to attempt to reduce the fishing effort, as the principal production and commercial procurement activity. However, this poses the question, on the one hand, of the professional reconversion of human resources and, on the other, of the safeguarding of the environment and the containment of negative externalities. Fish farming, feasible in both internal and marine waters, can still raise environmental problems, which must be carefully monitored. The negative environmental effects that can be found are related to the intensity of the fish farming operations while the main causes of environmental impact are attributable to feeding and the hygienic conditions of the farms, as set out below, in relation to the use of:

- feed and the subsequent catabolic release;
- antibiotics, antiparasitics and bacteriostatics;
- disinfectant products, biocides and disincrustants.

and the concentrations of products of animal catabolism.

The effects that the use of chemical products can generate are:

1. toxic action with acute mechanisms;
2. toxic action with chronic mechanisms;
3. the increase in biological oxygen demand (BOD);
4. the eutrophication of the receiving waters;
5. suspended solids.

In addition to the foregoing environmental effects there are a series of more general interactions with the natural environment. These effects refer to the production of waste (spent oils, plastic, special laboratory waste...) generated during the fish production/ processing cycle, and at present governed and constrained by special laws and regulations, as well as discarded produce, such as, for example, dead fish (either involuntarily released with waste water discharges or disposed of by specialised companies).

It can be stated that by introducing fish farming and replacing fishing two main aspects come to the fore, one positive and the other negative:

1. Positive: it reduces the damage caused by the traditional fish catch as it introduces a sustainable production system that takes account of the whole biological cycle up to the consumption of the raw material "fish";
2. Negative: the intensity of the farming produces a chemical impact on the environment and releases types of pollution that are often incompatible with the self-regenerating cycle of the environment.

The positive aspects can be further enhanced by some landscaping, tourist and recreational functions typical of some facilities (especially the extensive type which is more easily integrated into the environment), the increase in resources for angling and the provision of food for piscivorous bird fauna.

Some of the negative effects on the environment due to intensive fish farming can be limited by appropriate management and plant operation choices, among which:

- the use of low-environmental impact feed;
- the use of distribution techniques designed and situated to avoid waste;
- the controlled turnover of the water;
- the periodic removal of the sediment at the bottom of the tank and its possible recycling;
- the maintenance of a good level of oxygenation even in the deepest parts of the tank;
- controlling the water temperature with appropriate turnover of the water and the possible installation of covers;
- the use of filtering systems;
- controlled waste management (chemical, biological and dead fish).

In addition to introducing these arrangements in plant management, limiting environmental impact requires, first and foremost, the constant monitoring of incoming and outgoing water. It is obvious that this operation is simple for land-based facilities as there are specific arrival and discharge points for water. At sea, on the other hand, the operation is more complex and account must be taken of the prevailing currents and winds.

At this point it would be appropriate to present an Italian case in which lagoon fish farming is compatible with the lagoon environment. Operations such as the "Nord Adriatica" lagoon fish farm are models of extensive fish farming that also promote the conservation of sensitive environments.

The lagoon facilities, especially those of the coastal belt of the Upper Adriatic, have always sustained many activities (fishing, hunting, agriculture, artisanship, tourism) that share a strong dependency upon the environment and which are reciprocally compatible in their functions. The centuries-long practice of lagoon fish-farming, (vallicoltura : lagoons created by building barriers in marsh or wetland) which represents an efficient productive use of marshland, has made a significant contribution to this environment up until our own times. Not only does the habitat retain its natural characteristics, but these operations also constitute an important source of revenue for the surrounding territory, to which generations of lagoon fish farmers have contributed through the expert administration of both productive and environmental resources (Donati, 1992).

At present, the lagoon areas created by barriers (valli) have reached a reasonable equilibrated state, due to an appropriate interaction between the territory, the natural state of the physical elements, the water system and economic activities. Actually the need to safeguard natural components involved in lagoon fish farming and wetlands has been recognised recently, including an "active" management which fishing and fish farming can provide. The equilibriums established in the course of centuries are clearly delicate and the impact of external factors does certainly not favour conditions of stability.

A full understanding is therefore needed of the productive processes at play in these lagoon areas if we are not only to determine the conditions for their reproducibility in relation to new environmental situations, but also permit the development of "complementary factors" in the use of environmental resources. Thus, it should be noted that the constraints, introduced by the legislator purely aimed at the protection of the resources, would actually compromise the many forms of interdependence that have, hitherto, made it possible to avoid the excessive intensification of one productive activity at the expense of others. This is the case of fish farming, which has been widely introduced in lagoon areas. In Emilia, it was decided to maintain the original multi-functional facility and accentuate integrated forms of management. Integration and multi-functionality are, therefore, aspects that can enable more than any others the internalisation of the inevitable environmental maintenance costs, which progressively increase as fish management becomes more intensive.

Fish farm facilities can be designed in different way, each with a different environmental impact and consequently different sustainability improvements:

1. extensive: this is a characteristic of lagoon fish farm habitats and is conducted in both marine and brackish lagoon waters. An extensive farm means a farm in which nutriment is acquired totally from the trophic network of the environment without any external input. In this case men take care of environmental health questions. There is no doubt that this type represents an efficient synergy between productive factors and the safeguarding of environmental resources. The main constraints concern the yields as they are limited with respect to the capital and land locked up. For these reasons, extensive fish farms are often complemented by other activities such as hunting, angling and, more recently, rural tourism. The average production can be estimated as between 50 and 300 kg/hectares.
2. semi-intensive: The principal difference with respect to the preceding type of farming is that supplementary nutriments are administered in addition to the natural nutriment of the fish. As a rule the elements introduced have a limited proteinic content and/ or are agricultural side-products. Usually production does not exceed 4 t/hectare.
3. intensive: this type of farming is wholly dependent upon artificial nutriment and other production factors. Its development is modelled on the example of trout fish farms and large-scale use has been made of sophisticated feeding and water-oxygenation technologies. Intensive farm facilities in Italy are mainly represented by facilities with artificial basins where a single species with high biomass concentrations (circa 10/30 kg/m^3) is farmed.

Various factors have contributed towards the spread of intensive fish farming, including the use of techniques tried and tested in traditional animal husbandry, enriched by advance experimentations specific to the sector. In addition, animal feed techniques have been able to sustain the increases requested by the farms by proposing such innovative products as extruded feeds able to provide ever higher energetic quotas, along with the good digestibility of the proteinic element thus ensuring that nutriment levels in the fish farm and plant discharge water are kept within legal limits. Side by side with the research for animal feed, fish rearing technologies have been implemented that have led to the introduction of water oxygenation systems for the control of chemical-physical parameters of the water.

5. Some empirical evidence

After this analysis of the relations between economic and environmental needs, we would like to conclude with a case study. In the first part we shall briefly dwell on the trend in the sales and prices of fish products in some Veneto markets - a region where lagoon fish farming has, for centuries, flanked fishing - and subsequently, make a comparison between the produce caught and the produce farmed (bream, mullet and bass).

On data provided by the wholesale markets of Venice and Chioggia, the sales trends of the fish were analysed over a sufficiently long period (figure 8 and 9). On average, in the three-year period 2001-2003 the total landed/ delivered product sold in the foregoing markets was 8,580 tons, overall, of which about 7,100 tons from the sea, 920 from lagoons and 560 from lagoon farming.

In the Venetian market, classified by operators as a "consumer market" even if it no longer represents a major reference point for the sale of fish from lagoons and the Upper Adriatic, the supply of lagoon farmed fish (at present about 1,500 quintals on average per year) accounts for 10% of total local production (sea, lagoon, valle salsa [lagoon fish farms]), even if supplies exhibit a highly irregular pattern. Thus quantities can vary from a minimum in the summer period to a maximum in the winter when, for bad weather or storms, sea fishing production is low or end-of-year festivities stimulate demand.

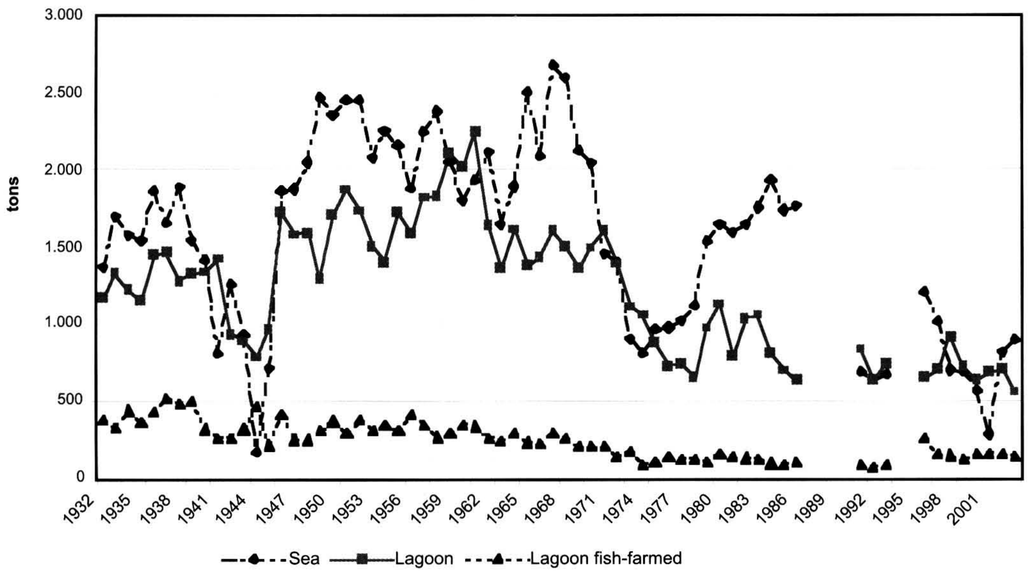
Lagoon fish farming, albeit with variations, has maintained a constant production trend from the 1970s to the present day. Sea and lagoon fished produce, on the contrary, underwent a strong decline in the period from 1980 to the present day, despite having exhibited strong growth in the period from the post-war to the 1970s, when they reached a peak of respectively 2,700 and 2,300 tons.

This growth in sea and lagoon fished produce was the result of new technologies (motorised fishing boats, refrigerator cells) that caused a significant increase in the catch. However, these technologies did not influence lagoon fish farming, which, as is known, depends wholly upon the characteristics of the closed lagoon habitat.

The steep fall off in production for lagoon fish farms in the mid 1970s and the 1980s was the result of events that led to dystrophic conditions. Instead, the strong decline in sea-fished produce during the last decade was mainly the result of the over-exploitation of the resource. In the case of the lagoon fished produce, on the other hand, the decline is attributable less to the scarcity of product than to the heightened interest of fishermen in Tapes Philippinarum[3] (2), whose production, inso-

[3] This species, which originally came from the Pacific, was introduced in 1983 in the Lagoon of Venice and later in other places in Italy for commercial reasons. Philippinarum shellfish, which are very similar to their indigenous congener decussatus, are now more common. The difference with respect to the autochthonous Tapes decussatus is not apparent to the non-expert. Essentially, it refers to the form of the shell, which is shorter, bulkier and with a ligament margin forming a less smooth angle with respect to the rear border

Figure 8. *Quantities sold in the Venice fish market by origin (sea, lagoon fish farm)*



far as it is not sold through the market, has not been recorded among the lagoon shellfish produce. Moreover, the collection/trawling of this shellfish by destroying the grounds or lagoon floor, has caused serious damage to the ecosystem of the lagoon and consequently comprised the production of lagoon fish.

Similarly, the analysis of the historical trends of the Chioggia market reveals a variable production trend (figure 9). A tendential growth trend can be noted up until the first years of the 1980s, followed by a substantial reduction in catches in the following twenty years.

While lagoon-farmed produce, albeit with major oscillations, reveals a more or less constant trend of about 350 tons per annum, marine and lagoon fished produce has rapidly declined in the last two decades. At present sea fished produce amounts to about 6 thousand tons with respect to the 16 thousand tons recorded at the start of the 1980s, while lagoon fished produce fell, in the same time period, from over 2 thousand to little more than 200 tons.

In 2003 total landed produce sold through this market was, overall, 10 thousand tons, of which 6,700 tons produced locally and 3,300 imported from other national and foreign markets. The local produce is made up for 90% by sea fish, 6% by lagoon-farmed fish and almost 4% by lagoon fish.

The preference of lagoon fish farmers for the Chioggia market is interesting. The companies seem to attribute more importance to this market, where the quantity of fish sold is double that of Venice, even if, generally speaking, it is more distant. The reasons for this preference are mainly to be sought in the greater flexibility and functionality of the structure and greater price stability (Boatto et al., 1985).

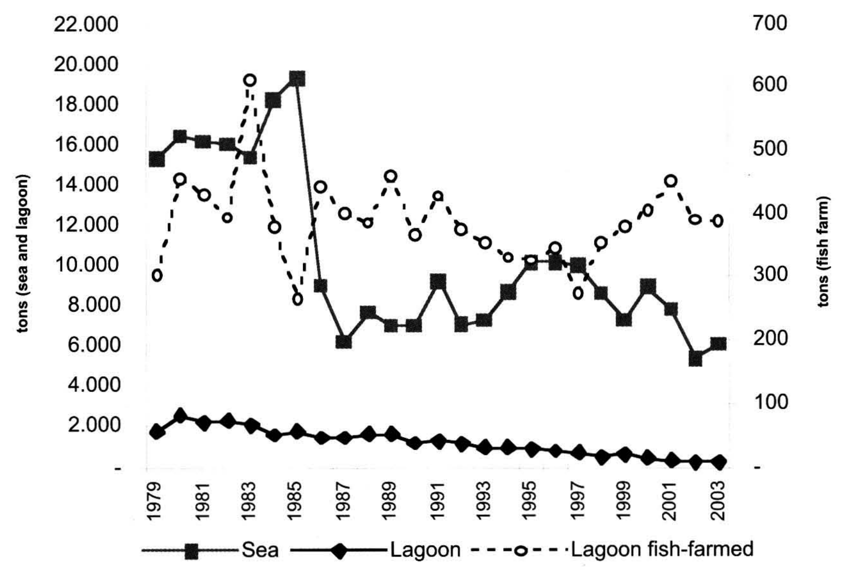
The bass and seabream sold in the market in question are almost wholly lagoon fish farm produce. On the other hand, mullet, in recent years is mainly sea fished produce.

The data allow us to obtain indications on the variability of the quantities sold on the market and the consequent variability in prices. It should also be noted that the sales curves referring to lagoon fish-farmed produce peaks in the autumn and dips to a minimum in summer. Consequently, the prices are highly unstable: the minimum level is reached in the autumn and the maximum in the three months of June, July and August.

It can be noted that, in general, the profitability of marine species (despite a brief rally in the last few years), especially seabream, has undergone a considerable reduction due to the competition from lagoon fish farms, intensive fish farms and imported produce. However, it is worth stressing that the prices of lagoon fish-farm bream and mullet are notably higher than those fished at sea.

However, given that most of the production of lagoon fish farms does not pass through the markets, their quotations could actually be different with respect to their market prices.

Figure 9. *Quantities sold in the Chioggia fish market by origin (sea, lagoon, fish farma)*



In addition to problems of excessive exploitation, which will not allow for the increase in the production of some species in the future, there remains the undeniable problem for Italy of a strongly deficitary balance of payments for fish products. As regards the strong increase recorded in imports we can note that the imports of bream for example, from 1996 to 2000, rose 300% nationally.

For this type of fish, moreover, we have found a strong disparity between domestic production, notably limited, and high consumption levels (especially if we consider that extra-domestic consumption has not been included).

With regard to the growth in consumption, on the other hand, we should note that about 56% of the world's population obtains at least 20% of their dietary animal protein from fish. According to FAO estimates, there will be a significant increase in the demand for fish produce in relation to the increase in the world's population. Therefore, average worldwide per-capita consumption could grow from 16 kg to 19-21 kg by 2030. And in view of the fact that fish catches will remain virtually stable, on account of the excessive exploitation of natural stocks, the difference between the resources available and increased demand can only be made good by fish farming.

6. Conclusions

Fishing is by now generally recognised as one of the causes of the change in marine biodiversity, and, in some cases, the departures from the equilibrium state of the ecosystems and the serious losses of economic and ecological resources. In order to implement a more rational management of biological resources the scientific community is slowing shifting from the "populationistic" approach, based on a single species target, to a holistic approach that addresses the far- reaching ecosystemic effects that fishing has upon the trophic chain as well as upon the interaction between the species, the structure and dynamics of the populations, the effects on non-commercial species and the physical environment. This new approach entails that the characteristics of the territory must be exploited in a more equilibrated manner by favouring the economic activities that can best adapt themselves to the requirements of a modern environmental policy.

Without doubt fish farming represents an important example of the possibility of [non-harmful] interactions between human activities and environmental conservation and, at the same time, an economically valid development model. However some scholars (Naylor et al., 2000) underline what they see as the inherent paradoxes of this activity. In their view it represents a possible solution to the excessive exploitation of some stocks and the problem of the disparity between the availability of resources and potential demand, but at the same time it is also a factor leading to the collapse of the stocks on account of the discharge of pollutants. Yet fish farming production systems are different and their impact can, consequently, be very different on the activities of the ecosystem.

Extensive fish farms such as, for example, lagoon fish farms, where fish growth is exclusively related to natural productivity of the aquatic habitat, represent a model in which the interest of the operator not only concerns the organisms reared but also the environment. Such low-energy content farming methods, with respect to the more productive intensive systems, have the undoubted advantage of contributing towards environmental conservation, whose maintenance in an optimal state lies at the basis of the company's economic viability.

References

Antonelli G. et alii (2002), Modelli teorici e principi guida per uno sfruttamento sostenibile delle risorse nel settore della pesca, in Trevisan G. (a cura di), Sviluppo sostenibile ed efficienza economica nel settore ittico Atti del III Convegno di Studi, Venezia, 15-16 ottobre, 2001.

AAVV. (1994). Parliamo di Acquacoltura. Atti Convegno Internazionale, Fossano (Cuneo), 13-14 ottobre.

API - Associazione Piscicoltori Italiani (2000). Studio sulle prospettive dell'acquacoltura nella Comunità Europea. Verona.

Boatto V., Signora W. (1985). Le valli da pesca nella laguna di Venezia, Università degli Studi di Padova, Istituto di Economia e Politica Agraria, Padova.

Botsford L. et alii (1997). The Management of Fisheries and Marine Ecosystems, in Science, 277: 509-515.

Castellini A., Ragazzoni A. (2002). Contabilità ambientale d'impresa in aziende ittiche: dalla produzione alimentare ai servizi ricreativi e di tutela ambientale, XXXIX Convegno SIDEA - gruppo di lavoro Gruppo di lavoro "Economia e politica del settore ittico", Firenze.

Ciani A., Cocco S. (1995). Sviluppo sostenibile: dal micro al macro. presentata alla Conferenza del Prof. D. Pearce "Sviluppo sostenibile: quali contenuti?", Facoltà di Agraria, 16 gennaio 1996, Perugia.

Commissione Mondiale per l'ambiente e lo Sviluppo (1988). Il futuro di noi tutti. Bompiani, Milano.

Donati F. (1992). Valutazione economica delle funzioni produttive delle valli da pesca. Genio Rurale, n. 5.

Fedrizzi M., Menesatti P. (1994). L'acquacoltura intensiva in Italia: considerazioni normative, economiche e nuove prospettive di ricerca. Informatore Agrario, n. 37.

Granzotto A. et alii (2001). La pesca nella laguna di Venezia: un percorso di sostenibilità nel recupero delle tradizioni. Lo stato dell'arte. Rapporto sullo sviluppo sostenibile, n.2, Fondazione Enrico Mattei.

ISMEA (1997). Pesca e Acquacoltura. dicembre, Roma.

ISTAT (1996). Contabilità ambientale. Roma.

Jeremy et alii (2001). Historical overfishing and the recent collapse of coastal ecosystems, in Science, 293: 629-638.

Mauracher C. (2003). La vallicoltura nella Laguna veneta tra passato e presente. Aspetti storici, sociali, di economia ed estimo dei territori vallivi in ambiente lagunare, Rivista Genio Rurale - Estimo e Territorio, Edagricole n.1.

Melotti P., Roncarati A., Mordenti O. (1999). L'acquacoltura oggi e domani: quadro mondiale, europeo e situazione italiana. Acquacoltura e pesca tra i due millenni, I Georgofili. Quaderni, II.

Melotti P. (1999). L'attività di acquacoltura in Italia, Convegno Aggiornamento su farmaci e vaccini in acquacoltura, 9° Salone Internazionale dell'acquacoltura, Verona 13 febbraio 1999.

Pearce D. (1996). Sviluppo sostenibile: quali contenuti?. Conferenza presso la Facoltà di Agraria, 16 gennaio 1996, Perugia.

Pearce David W., Turner R. Kerry (1991). Economia delle risorse naturali e dell'ambiente. Il Mulino, Bologna.

Tiezzi E. (1988). Tempi storici e tempi biologici. in Ceruti M., Laslo E. (a cura di), "Phisis: Abitare la Terra", Feltrinelli, Milano.

Trevisan G. (a cura di). Il prodotto ittico: Aspetti economici e statistici, Atti del I Convegno di Studi, Venezia, 28-29 settembre, 1999.

Trevisan G. (a cura di). Il prodotto ittico, Consumo, Qualità, Commercializzazione. Atti del II Convegno di Studi, Venezia, 11-12 ottobre, 2000.

Trevisan G., Mauracher C. (a cura di), Sviluppo sostenibile ed efficienza economica nel settore ittico, Atti del III Convegno di Studi, Venezia, 15-16 ottobre, 2001.

Trincanato A. (1997). Alcune valutazioni sullo sviluppo dell'acquacoltura in Italia, Informatore Agrario, n. 4.